

Landsat 9

Briefing to the Landsat Science Team

July 26, 2016



Del Jenstrom
Landsat 9 Project Manager
NASA Goddard Space Flight Center



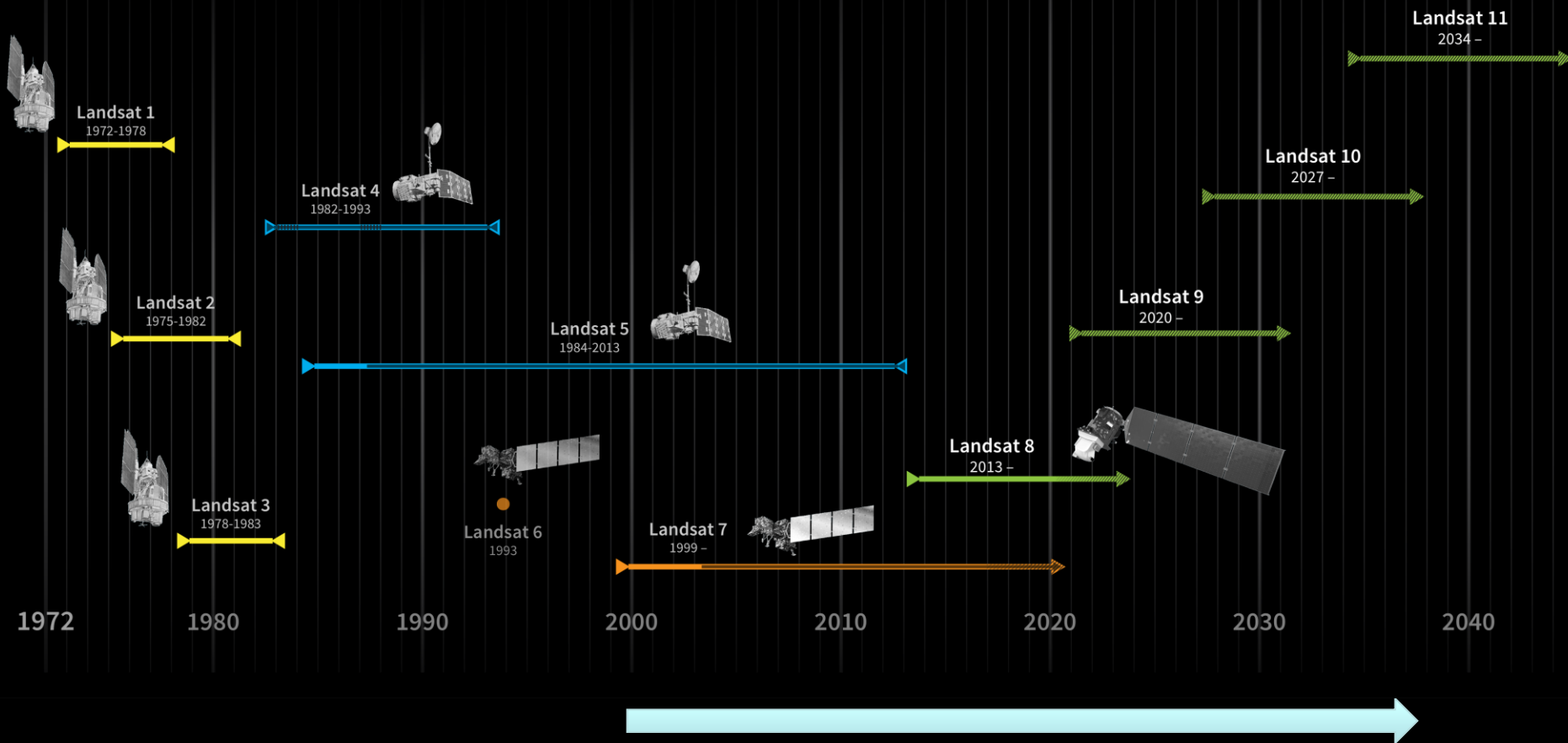
Jim Nelson
USGS Landsat 9 Project Manager
USGS EROS Center

Landsat 9 Background



- The President's FY 16 Budget Submittal to Congress (February 2015) included Landsat 9 as the first flight element of the Administration's Sustainable Land Imaging (SLI) program.
- The Earth Science Division (ESD) issued a Project Authorization Letter to GSFC on March 4, 2015 to establish a Landsat 9 Project Office and to provide direction on FY 2015 activities.
- Landsat 9 was included in the FY 2016 Appropriations Act.
 - Language included in the "Joint Explanatory Statement to accompany the Consolidated Appropriations Act, 2016" directed NASA to accelerate the Landsat 9 development schedule with a target launch date in calendar year 2020.
- The President's FY 17 Budget Submittal to Congress (February 2016) included Landsat 9, with a launch as early as FY 2021.
- The Project has been directed to strive for a late CY 2020 launch date to the extent possible, while remaining consistent with agency policies, available budgetary resources, and the risk posture appropriate for this Category 1/Class B mission.

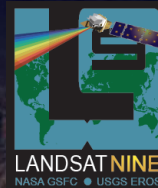
BUILDING ON THE LANDSAT LEGACY



NASA-USGS Interagency Partnership

- NASA: Space Segment and Launch
- USGS: Operations & Data Processing/Distribution

Landsat 9 Heritage



- Landsat 9 is substantially a rebuild of Landsat 8, using Landsat 8 designs and subsystems to the extent possible to minimize cost, schedule, and risk.
 - Rebuild of the Operational Land Imager (OLI)
 - Rebuild of the Thermal Infrared Sensor (TIRS), with changes to TIRS only to upgrade the instrument to Class B reliability standards and to address known performance issues with the Landsat 8 TIRS
- Landsat 9 mission objectives and Level 1 Requirements are essentially identical to those for Landsat 8.
 - Major exception - TIRS-2 requirements are now included in the baseline science requirements for Landsat 9.
- High degree of heritage enables Landsat 9 to begin in Phase A (rather than Pre-Phase A)
 - Mission Concept Review (MCR), Key Decision Point A (KDP-A), and Acquisition Strategy Meeting (ASM) omitted
 - Remainder of the formulation (Phase B) and development (Phase C/D) phases to be conducted in accordance with the standard NPR 7120.5E review processes following KDP-B

Landsat 9 Mission Overview



Mission Objectives

- Provide continuity in the multi-decadal Landsat land surface observations to study, predict, and understand the consequences of land surface dynamics
 - Land cover/use change
 - Ecosystem dynamics
 - Landscape scale carbon stocks
 - Resource management/societal needs
- Core Component of Sustainable Land Imaging Program

Mission Parameters

- **Single Satellite, Mission Category 1, Risk Class B**
 - 5-year design life after on-orbit checkout
 - At least 10 years of consumables
- **Sun-synchronous orbit, 705 km at equator, 98° inclination**
- **16-day global land revisit**
- **Partnership: NASA & United States Geological Survey (USGS)**
 - NASA: Flight segment & checkout
 - USGS: Ground system and operations
- **Launch: FY2021 (Targeting December 15, 2020), Category 3 Vehicle**

Instruments

- **Operational Land Imager 2 (Ball Aerospace)**
 - Reflective-band push-broom imager (15-30m res)
 - 9 spectral bands at 15 - 30m resolution
 - Retrieves data on surface properties, land cover, and vegetation condition
- **Thermal Infrared Sensor 2 (NASA GSFC)**
 - Thermal infrared (TIR) push-broom imager
 - 2 TIR bands at 100m resolution
 - Retrieves surface temperature, supporting agricultural and climate applications, including monitoring evapotranspiration

Spacecraft & Observatory I&T

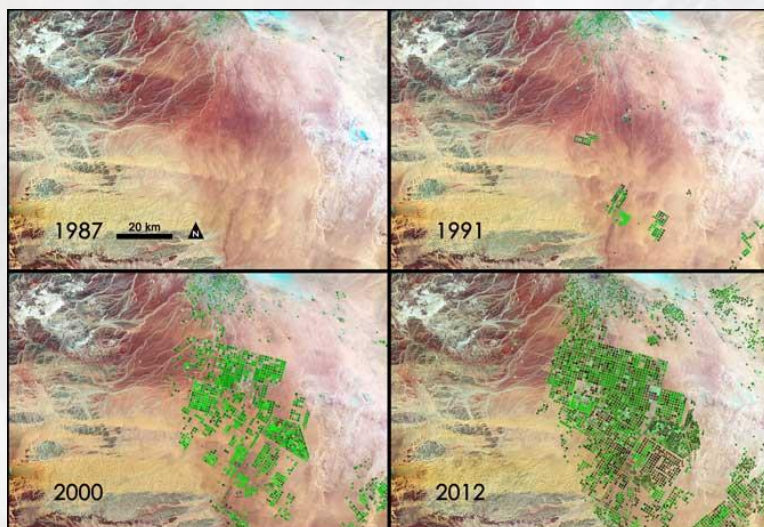
- **Competitively Procured: TBD**

Launch Services

- **Competitively Procured: TBD**

Mission Team

- **NASA Goddard Space Flight Center (GSFC)**
- **USGS Earth Resources Observation & Science (EROS) Center**
- **NASA Kennedy Space Center (KSC)**



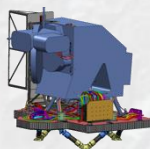
Increase in pivot irrigation in Saudi Arabia from 1987 to 2012 as recorded by Landsat. The increase in irrigated land correlates with declining groundwater levels measured from GRACE (courtesy M. Rodell, GSFC)

Mission Segments and Elements

Space Segment

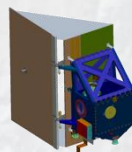
Operational Land Imager 2 (OLI-2)

- Multi-Spectral Imaging Instrument
- Pushbroom VIS/SWIR sensor
- Four mirror telescope
- Focal Plane consisting of 14 SCAs



Thermal Infrared Sensor 2 (TIRS-2)

- 2 thermal channels
- Pushbroom design
- Quantum well detectors
- Actively cooled FPA



Spacecraft

- 3-axis stabilized
- Accommodates OLI-2 & TIRS-2

Launch Segment

Competed via KSC LSP



Ground Segment

Mission Operations Center (MOC)

- Command & telemetry
- Trending & analysis
- Flight dynamics
- Science acquisition planning
- Primary and backup MOCs at GSFC
- (NASA is responsible for basic facility and launch support room costs prior to on-orbit acceptance)

Operations

- Flight Operations Team
- NASA leads (USGS supports) mission operations readiness activities, pre-launch, launch and early orbit activities
- USGS leads operations following on-orbit acceptance

Data Processing and Archive System (DPAS)

- Ingest, product generation, & image assessment/processing
- User Portal web interface for data discovery, product selection & ordering (for Cal/Val), & product distribution
- Storage and archive services

Ground Network Element (GNE)

- Ground stations/antennas for X-Band image & S-Band telemetry data downlink
- Generation of S-Band command uplink

Landsat 8/9 Improvements



- **Payload:**
 - Operational Land Imager (OLI, BATC) – Vis, Short wave IR (VSWIR)
 - Thermal Infrared Sensor (TIRS, GSFC) – Thermal IR (TIR)
 - 5-year mission design life; 10+ years of consumables
- **New spectral bands:**
 - 443 nm – improved coastal water, atmospheric correction
 - 1370 nm – cirrus identification & removal
 - Two TIR bands – better TIR atmospheric correction
- **Improved Signal to Noise Ratio (SNR) & dynamic range:**
 - Better biophysical retrievals
 - Coastal/water constituent applications
 - No saturation over bright targets
- **More Data:**
 - USGS acquiring ~740 scenes/day (vs 400 required)
 - Better intra-annual dynamics, reduced cloud impact



Level 1 Requirements: Changes from LDCM

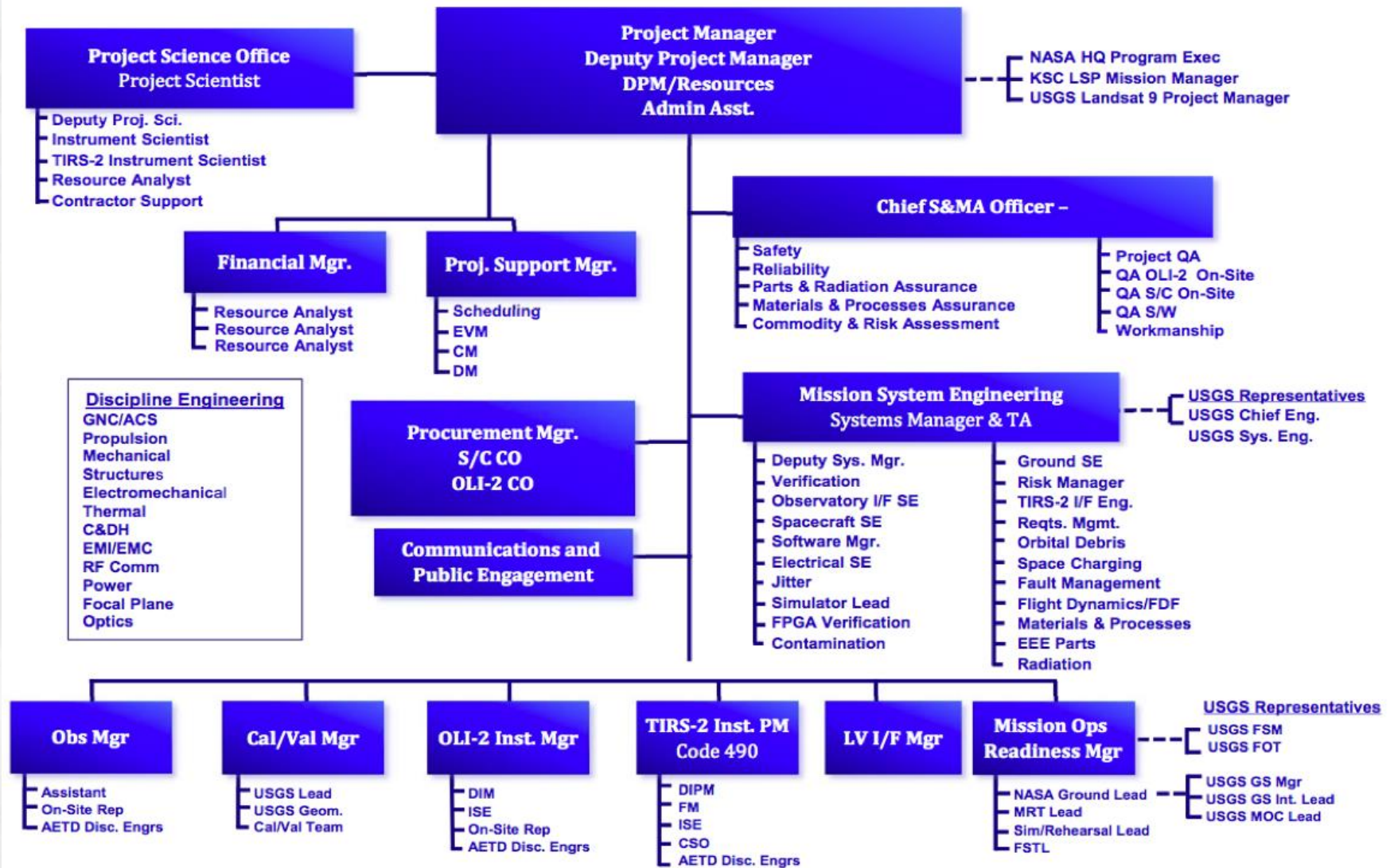
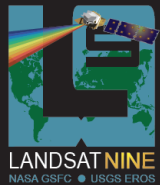
- **Program Level Requirements Appendix (PLRA) contains Level 1 requirements – baselined**
- **Landsat 9 Level 1 Requirements are mostly identical to LDCM**
 - Mission Category 1
 - Risk Class B
 - Category 3 Launch Vehicle
- **Primary Differences:**
 - Whole mission is categorized as Class B, with no exception for TIRS
 - Requirements for TIR observations now included in Threshold Science Requirements
 - Threshold Requirements are identical to Baseline Requirements
 - Landsat 8 Threshold requirements were “VSWIR only”
 - Data acquisition requirement maintained at least 400 scenes per day, but PLRA language supports current, higher capability: *“Recognizing that the actual performance of Landsat 8 yielded capacity to acquire substantially more than the minimum 400 scenes/day, for Landsat 9 there should be no spacecraft or instrument design changes that would diminish the mission’s capacity to acquire as many scenes per day as Landsat 8 has demonstrated.”*
 - Requirement for High Priority Acquisitions deleted (no longer needed)
- **Launch Readiness Date Updated**
 - *“...the Landsat 9 project shall strive for a late [CY] 2020 launch date to the extent possible, while remaining consistent with agency policies, available budgetary resources, and the risk posture appropriate for this Category 1/Class B mission”*

Level 1 Requirements

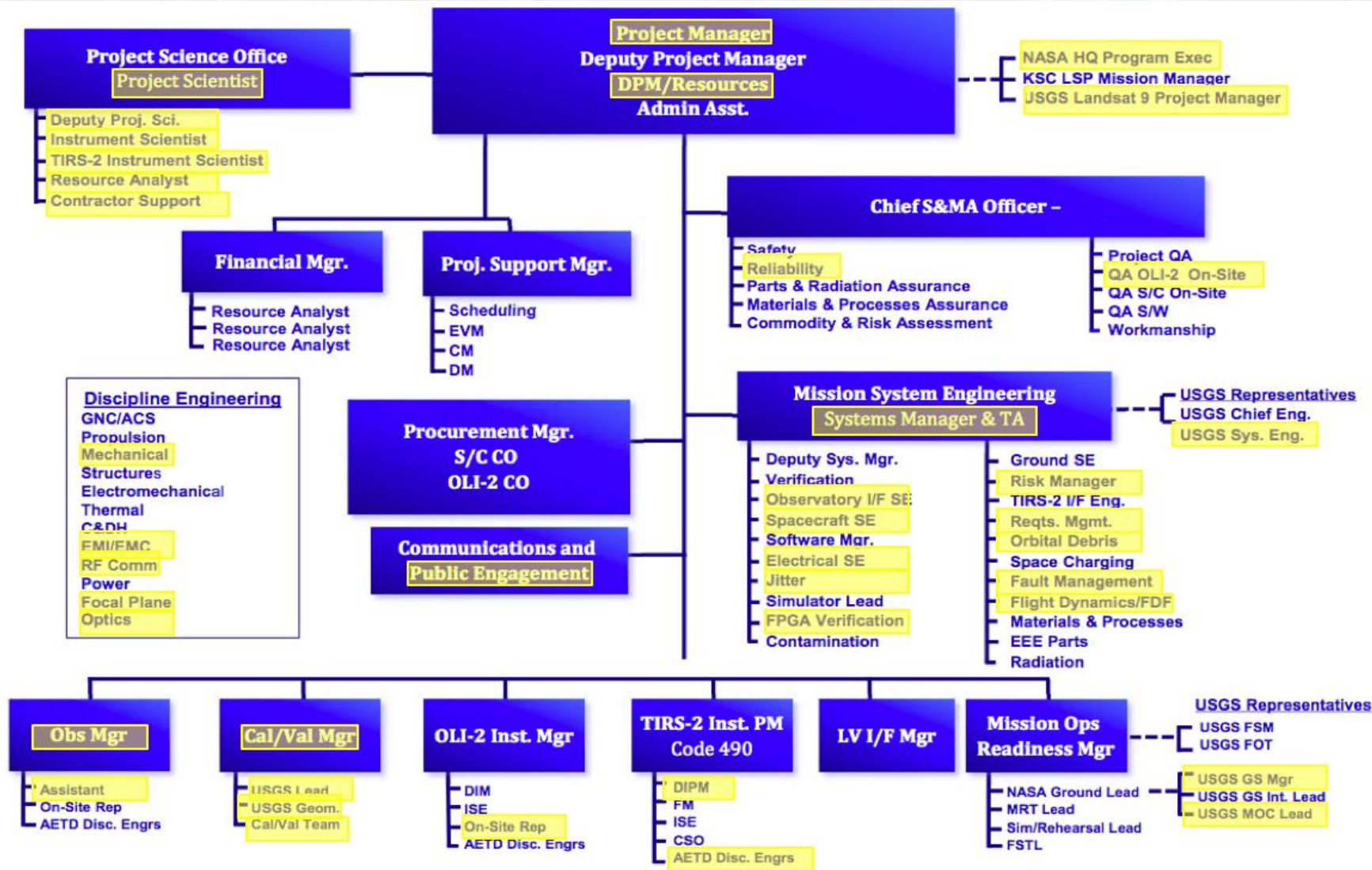


- **Category 1, Risk Class B Mission**
 - Category 3 launch vehicle
- **Threshold Requirements Equal To Baseline Requirements**
- **Strive For Late 2020 Launch Date**
- **Mission Lifetime**
 - At least 5 years; at least 10 years consumables
- **Acquisition Geometry**
 - Collect along heritage Landsat ground track
 - 10 AM +/- 15 min equatorial crossing time
- **Coverage Characteristics**
 - Image any sunlit area at least once every 16 days
- **Spectral Bands**
 - 9 heritage reflective bands
 - 2 heritage thermal bands
- **Spatial Resolution**
 - 30 m (15 m panchromatic)
 - ≤ 120 m thermal
- **Geometric Performance**
 - Orthorectified images
- **Radiometric Performance**
 - Data that transform linearly to top-of-the-atmosphere spectral reflectance (bands 1-9), radiance (bands 10-11)
 - Absolute radiometric uncertainty
 - $< 5\%$ bands 1-9
 - $< 2\%$ bands 10-11
- **Scene Collection/Generation Rate**
 - At least 400 scenes per day
 - Do not diminish ability to match Landsat 8 capabilities
- **Public Access**
 - Nondiscriminatory; no cost to user
- **Algorithm Release**
 - Publicly release data processing algorithms
- **International Cooperator Support**
 - Transmit real-time data to multiple international cooperator ground stations
- **Public Outreach**
- **Landsat Science Team**

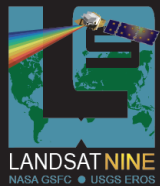
Landsat 9 - Project Organization



LDCM Experience on Landsat 9

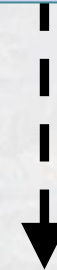
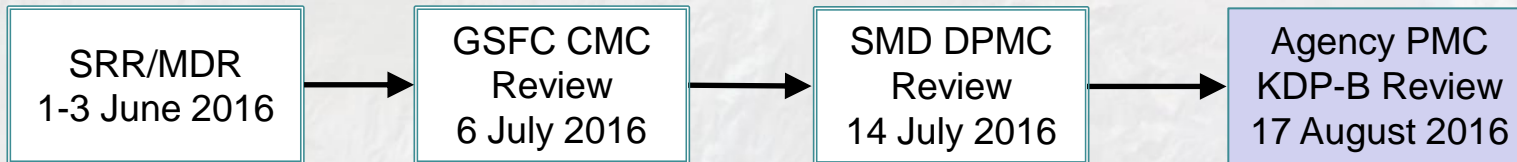
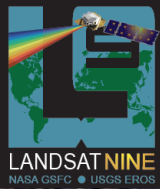


Landsat 9 Accomplishments



- **Project Authorization, March 4, 2015**
- **Project staffing begins**
- **Initial recommendations for formulation presentation to HQ ESD, May 8, 2015**
- **TIRS-2 instrument project forms, June 2015**
- **Landsat 9 Kickoff Week, June 15-19, 2015**
- **Center Monthly Status Review (MSR) reporting commenced, July 15, 2015**
- **OLI-2 Procurement Strategy Meeting, August 17, 2015**
- **OLI-2 Sole Source Approval, September 1, 2015**
- **Spacecraft Study Request For Offer (RFO) Release via Rapid S/C Dev. Office (RSDO), November 2, 2015**
- **OLI-2 Sole Source Request For Proposal (RFP) Release, November 5, 2015**
- **TIRS-2 Instrument Heritage Review, November 19, 2015**
- **Spacecraft Study Contracts awarded via RSDO, December 18, 2015**
- **OLI-2 Letter Contract Award to Ball Aerospace & Technologies Corp. (BATC), December 30, 2015**
- **USGS RFI Released for Landsat Mission Operations (LMO) contract, January 26, 2016**
- **USGS Landsat 9 Ground/Ops Industry Day, February 2, 2016**
- **OLI-2 Letter Contract Definitization, February 22, 2016**
- **Spacecraft Study Contract Reports Delivered, March 18, 2016**
- **Spacecraft Draft RFO released to study vendors via RSDO, March 28, 2016**
- **OLI-2 Instrument Heritage Review, April 12-13, 2016**
- **TIRS-2 Cryocooler contract with BATC definitized, May 17, 2016**
- **Spacecraft Final RFO released to vendors via RSDO, May 18, 2016**
- **Landsat 9 System Requirements Review / Mission Definition Review (SRR/MDR), June 1-3, 2016**
- **Initiate spacecraft Source Evaluation Board (SEB), June 17, 2016**
- **Completed KDP-B Readiness Reviews with GSFC, ESD, and SMD in July (KDP-B planned for August)**

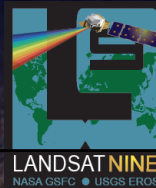
Landsat 9 “Road to KDP-B”



**Enter
Phase B**

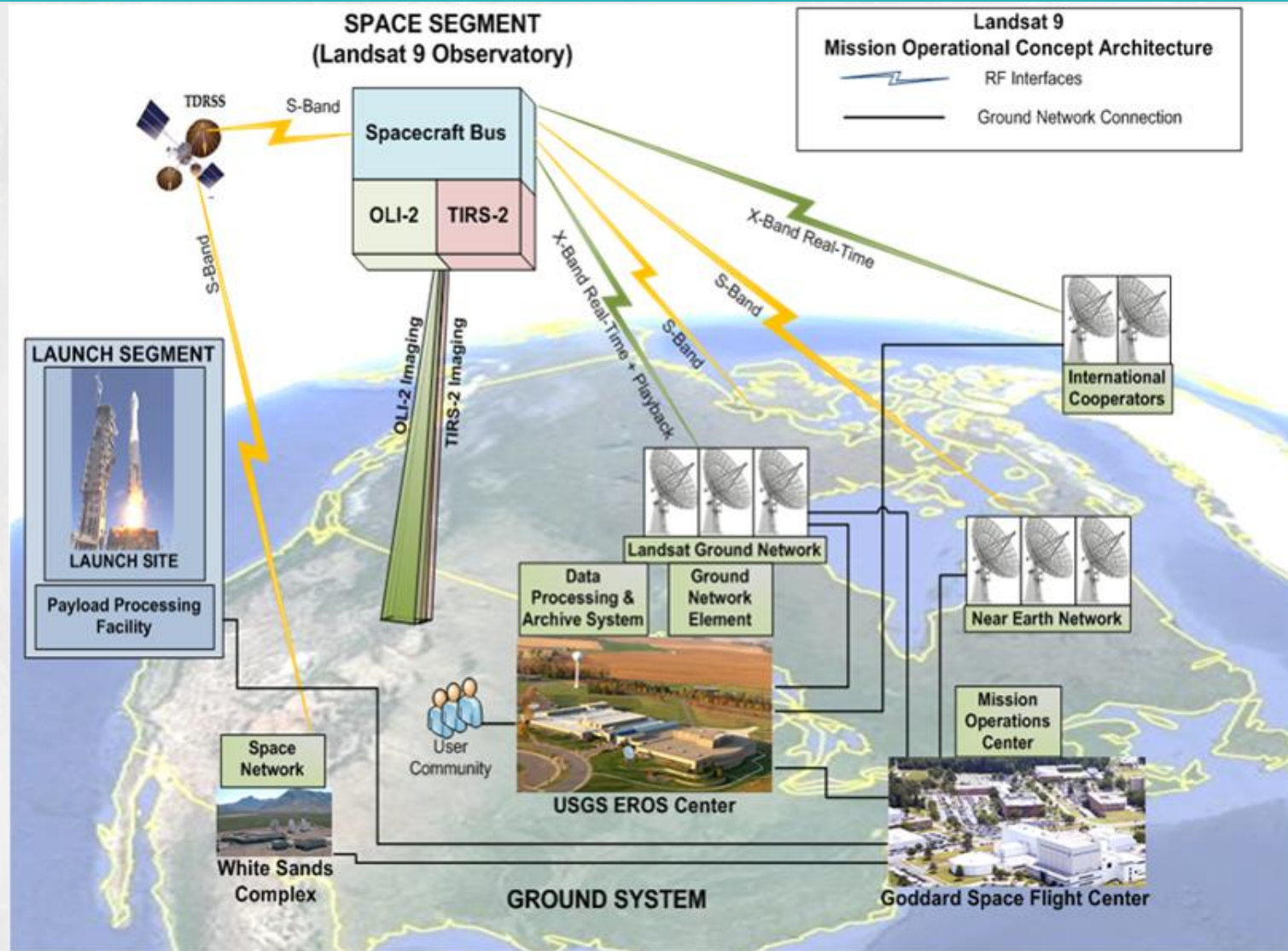


Landsat 9 Project Overall Status



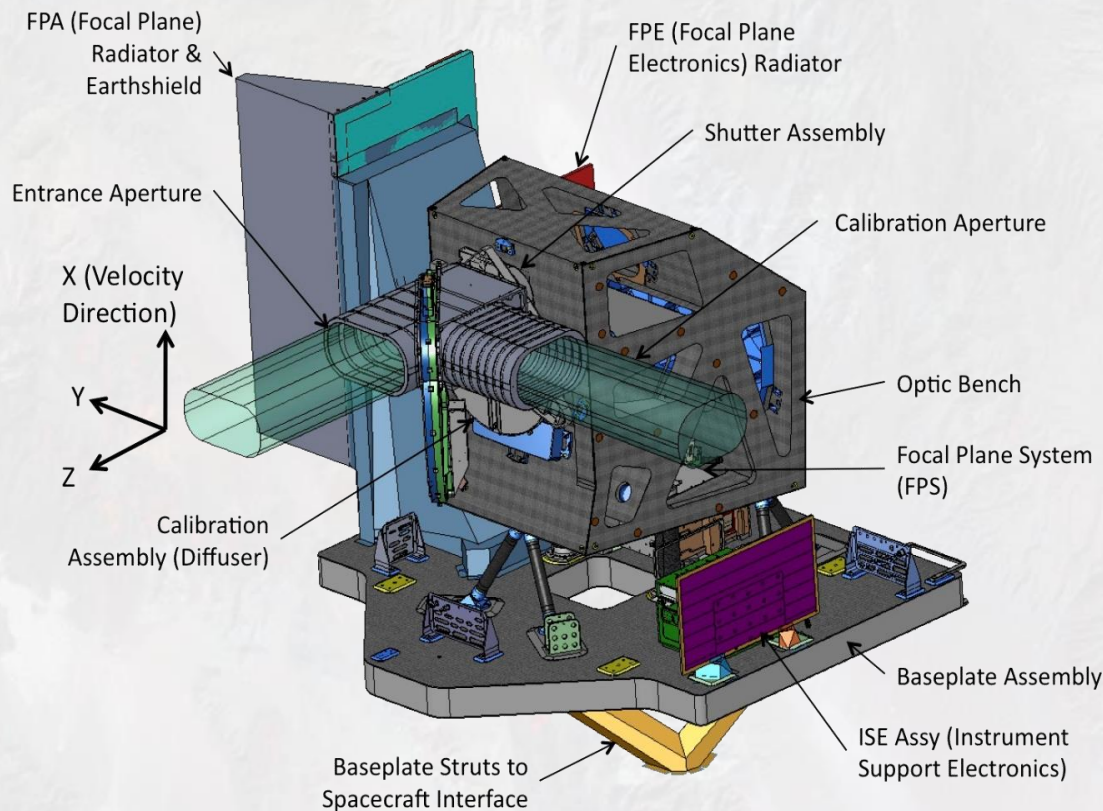
| Summary | Apr | May | Jun | Comments |
|----------------------|-----|-----|-----|--|
| Management | G | G | G | Held successful SRR/MDR June 1–3. The project was green across the board to success criteria except for the challenging schedule to launch in December 2020, which was rated as yellow. The SRB concluded that Landsat 9 is clearly ready to proceed into Phase B. Briefing to GSFC Mgmt. Council on July 6; ESD Briefing on July 7; Science Mission Directorate Mgmt. Council on July 14. All were successful. KDP-B planned for August 17 to Agency Mgmt. Council. |
| Cost | G | G | G | Overall cost is good. |
| Technical | G | G | G | Technical team supporting spacecraft SEB and instrument development. |
| Spacecraft | G | G | G | Spacecraft RFO released May 18 via RSDO. Vendor proposals received June 17. SEB underway. |
| OLI-2 Instrument | G | G | G | OLI-2 contract with Ball Aerospace established Dec 2015. Testing of flight Focal Plane Modules left over from LDCM underway; 10 completed so far look good. Instrument CDR scheduled for August. |
| TIRS-2 Instrument | G | G | G | Cryocooler build underway at Ball Aerospace and PDR completed. Encoder vendor under contract. Existing QWIP testing underway; prelim results look good. Successful TIRS-2 Instrument PDR in June. Instrument CDR planned for early 2017. |
| Ground / Mission Ops | G | G | G | Assisting USGS in development of the USGS Landsat Mission Operations (LMO) request for proposal (RFP). |
| Launch Vehicle | G | G | G | LV Interface Requirements Document is baselined. Working with HQ/ESD and KSC/LSP to establish LV acquisition schedule and competition details. |
| Science | G | G | G | Analyzing OLI-2 and TIRS-2 detector test data |
| Schedule | G | G | G | All project elements targeting a December 15, 2020 LRD |
| Reserves | G | G | G | Project-held reserves look good. |
| Overall | G | G | G | Successful SRR/MDR, Received S/C proposals and SEB underway. TIRS-2 held successful instrument PDR. |

Mission Architecture Identical to Landsat 8



Operational Land Imager 2 (OLI-2)

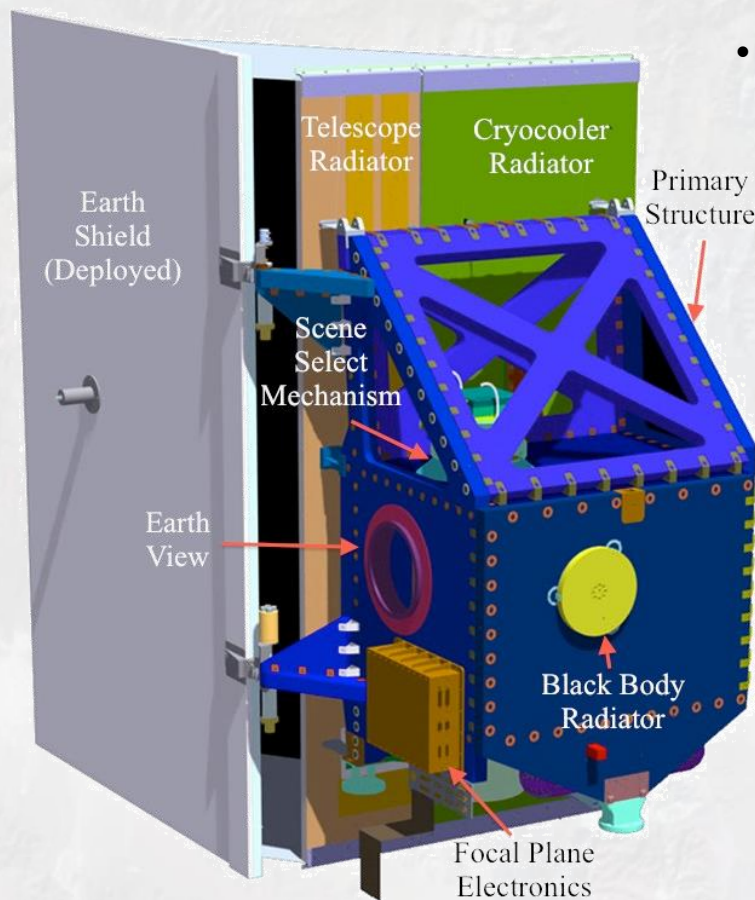
OLI-2 will, to the extent possible, be a copy of OLI for Landsat 9 to maintain data continuity with Landsat 8 and to minimize cost and risk



Assembled LDCM OLI at vendor's facility

Thermal Infrared Sensor 2 (TIRS-2)

TIRS-2 will be a rebuild of Landsat 8 TIRS except TIRS-2 will be upgraded from Risk Class C to Class B for Landsat 9



• Primary Risk Class B Improvements

- Redundant Main Electronics Box (MEB)
- Redundant Cryocooler Electronics (CCE)
- Cross-strapped MEB and Focal Plane Electronics (FPE)
- Addition of survival heaters

Other TIRS-2 Improvements

- Improved stray light performance through improved telescope baffling
- Improved position encoder for scene select mirror to address problematic encoder on Landsat 8 TIRS
- Potential improvements in thermal blanketing and coatings to better protect from micrometeorite/orbital debris (MMOD) impact and reduce charging
- Reviewing structural compliance to Atlas V Mass Acceleration Curve

Technology Assessment



- **Landsat 9 utilizes only proven technologies**
 - OLI-2 and TIRS-2 instruments have strong heritage to their predecessors on Landsat 8
 - Rapid Spacecraft Development Office (RSDO) spacecraft utilizes proven bus designs
- **Landsat 9 has no technology under development**

 **NEW TECHNOLOGY**

Landsat 9 Key Phase B Milestones



- **Mission**
 - Mission Preliminary Design Review, mid 2017*
 - KDP-C (Confirmation Review), mid-late 2017*
- **OLI-2**
 - OLI-2 Integrated Baseline Review (IBR), August 2016
- **TIRS-2**
 - TIRS-2 Critical Design Review, early 2017
 - TIRS-2 Integrated Baseline Review (IBR), mid 2017
- **Spacecraft**
 - Spacecraft Delivery Order Award, fall 2016
 - Spacecraft System Requirements Review, early-mid 2017*
 - Spacecraft Preliminary Design Review, mid-late 2017*
- **USGS Ground & Operations**
 - Ground System Heritage Review, late 2016
 - Landsat Mission Operations (LMO) Contract Award, early-mid 2017
 - Ground System Preliminary Design Review, mid 2017
- **Launch Vehicle**
 - Timing of launch vehicle procurement in work with HQ

* Milestone dates will be refined after award of spacecraft delivery order

NASA Summary / Conclusions

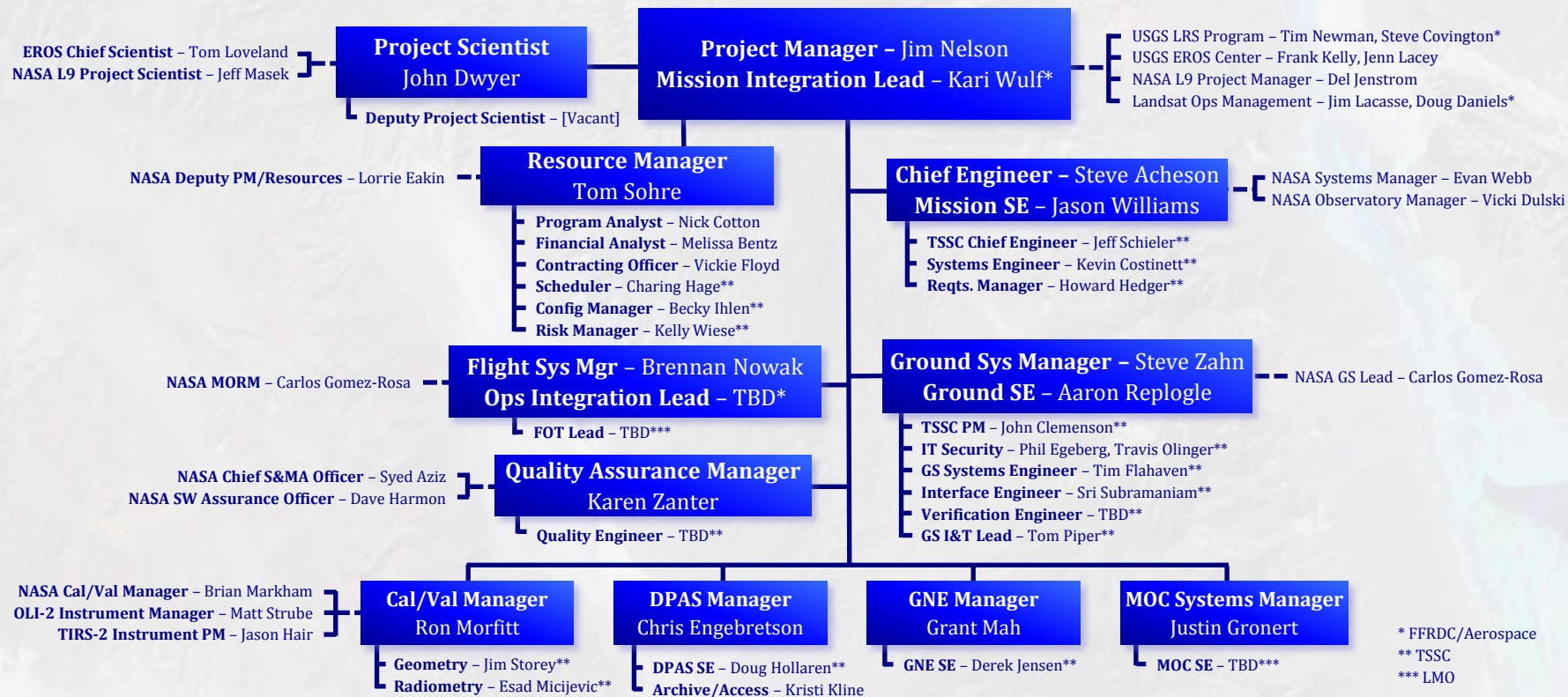
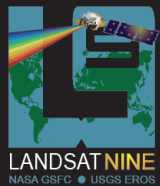


- **Landsat 9 project ready to move into Phase B**
- **All project elements are appropriately underway and making excellent progress**
 - Both instruments proceeding toward CDR
- **NASA and USGS budget planning fully supports project's needs**
- **Landsat 9 management processes firmly established and proven on LDCM**
- **Highly experienced and talented project team fully engaged**
- **Strong NASA-USGS relationship is well defined and operating effectively**
- **All key project products (e.g., requirements, plans, etc.) are at or above required maturity level**
- **Plan forward has been established**
- **Key lessons learned are being applied at all Project levels**
- **Targeting launch in December 2020, but will be challenging**
 - Everything has to go well

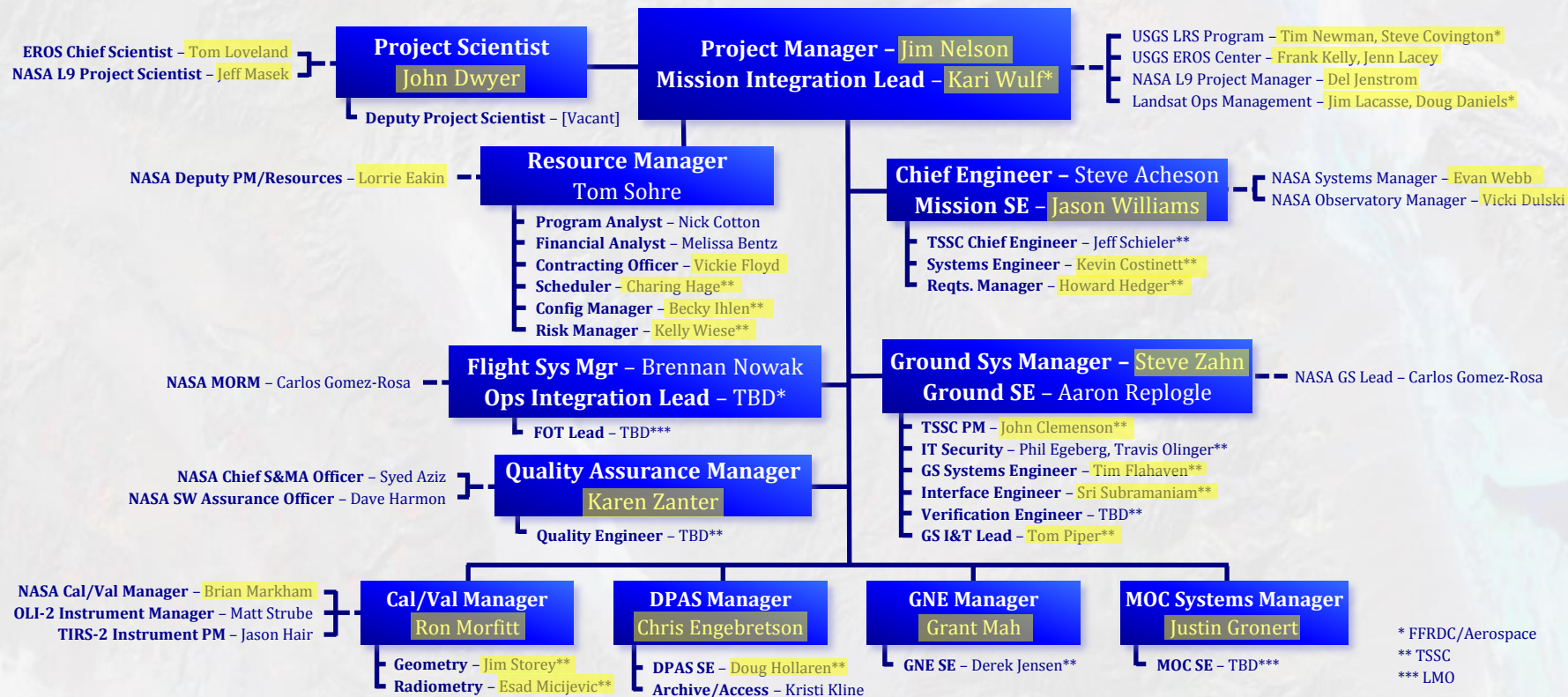
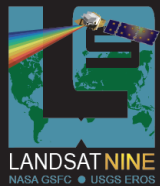
USGS Landsat 9 Project Status

Jim Nelson
USGS Landsat 9 Project Manager
USGS EROS

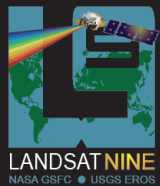
USGS Landsat 9 Project Organization



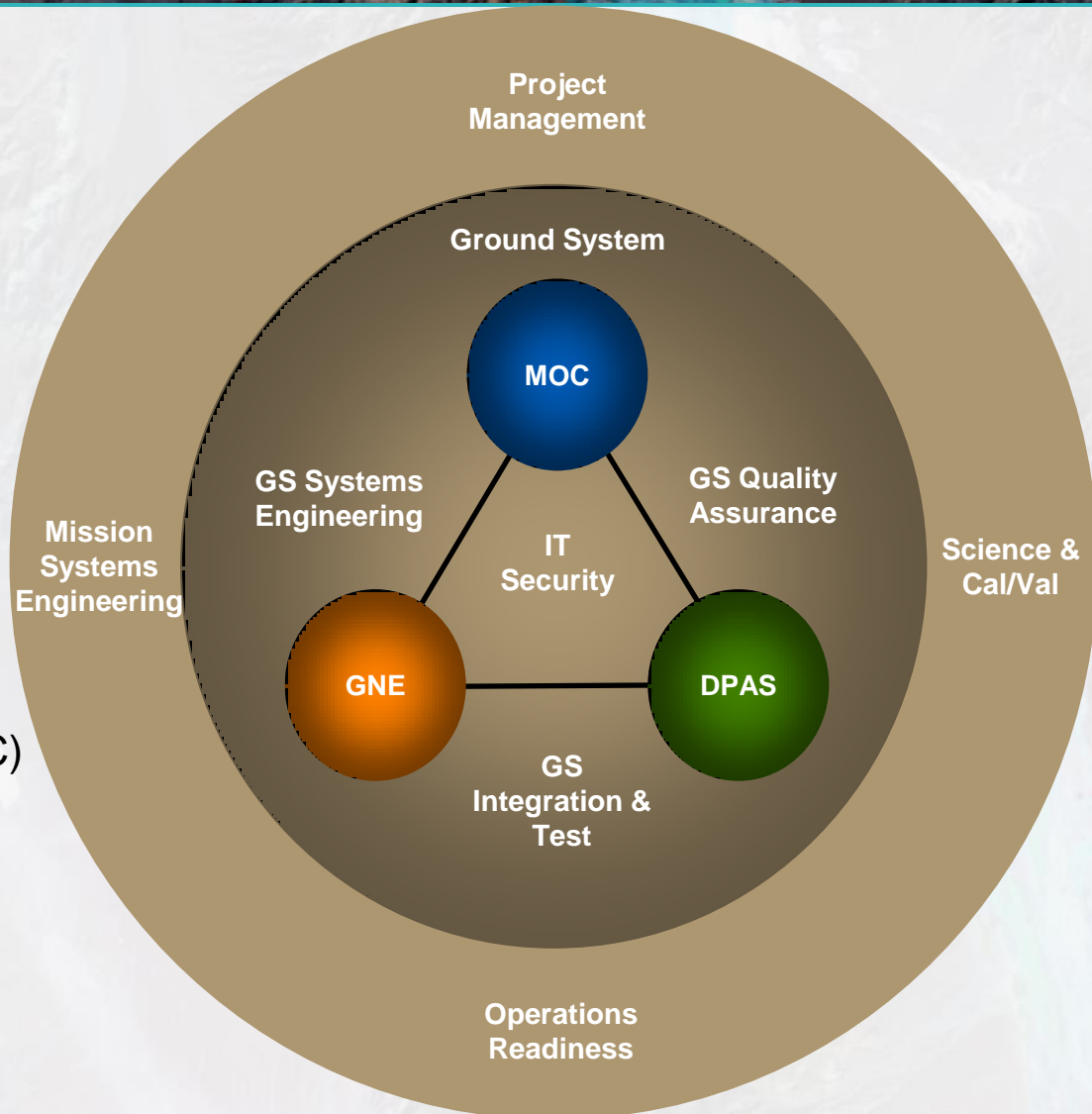
USGS Landsat 9 Team with LDCM Experience



USGS Landsat 9 Project Scope



- **Mission Partner – jointly support these activities:**
 - Project Management
 - Mission Systems Engineering
 - Science
 - Cal/Val
 - Operations Readiness
- **Ground System Developer**
 - Ground Network Element (GNE)
 - Data Processing and Archive System (DPAS)
 - Mission Operations Center (MOC)



Landsat 9 Ground System



- **Mission Operations Center (MOC)**

- Flight Operations Team (FOT) performs mission planning and scheduling, command and control, health and status monitoring, orbit and attitude maintenance, mission data management
- NASA provides MOC and BMOC facility at GSFC as well as NASA institutional services (SN, NEN, NISN, FDF) through on-orbit acceptance



- **Ground Network Element (GNE)**

- Landsat Ground Network (LGN) stations provide X- and S-band communications with the Observatory
- LGN stations in Sioux Falls, SD; Fairbanks, AK; and Svalbard, Norway
- Data Collection and Routing Subsystem (DCRS) gathers mission data from LGN stations into complete intervals to transfer to the DPAS



- **Data Processing and Archive System (DPAS)**

- Provides data ingest, storage and archive, image assessment, product generation, and data access and distribution
- DPAS facility at USGS EROS Center

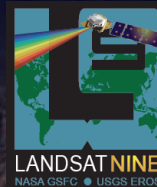


USGS Project Status



- **USGS Landsat 9 Project Plan is baselined**
 - USGS Configuration Management Board (in place) controls ground system, operations, and USGS project-level documents
 - USGS Risk Management Board (in place) manages ground system, operations, and USGS project-level risks
 - USGS Ground System and Operations Master Schedule completed with dependencies integrated with Landsat 9 Master Schedule
 - USGS Landsat 9 budget approved through USGS and DOI management
- **USGS releasing Landsat Mission Operations (LMO) contract in late CY2016**
 - Scope includes Landsat 9 MOC, Landsat 9 FOT, and Landsat 8 operations and sustaining engineering
 - RFI released 1/26/16, Industry Day 2/2/16, Industry 1-on-1s 3/21/16-3/25/16
 - RFP release expected late CY16 with award in spring 2017
- **Ground System Heritage Review planned for late CY16**
 - Will cover ground system requirements and heritage design components

Acronyms (1/2)



| | | | |
|----------------|--|-----------------|---|
| AETD | Applied Engineering & Technology Directorate | FIA | Final Implementation Agreement |
| ALI | Advanced Land Imager | FMECA | Failure Modes Effect Criticality Analysis |
| ALIAS | Advanced Land Imager Assessment System | FOT | Flight Operations Team |
| ASM | Acquisition Strategy Meeting | FOV | Field of View |
| ATP | Authorization to Proceed | FPA | Focal Plane Assembly |
| BATC | Ball Aerospace & Technologies Corporation | FPE | Focal Plane Electronics |
| BOE | Basis Of Estimate | FPE | Focal Plane Element |
| CAL/VAL | Calibration/Validation | FPGA | Field Programmable Gate Array |
| CAPE | Collection Activity and Planning Element | FPM | Focal Plane Module |
| CCB | Change Control Board | FY | Fiscal Year |
| CCE | Cryocooler Electronics | GIS | Geographical Information System |
| CDRL | Contract Data Requirements List | GNE | Ground Network Element |
| CLA | Coupled Loads Analysis | GOTS | Government Off the Shelf |
| CMC | Center Management Council | GPIO | General Purpose Input and Output |
| CO | Contract Officer | GRT | Ground Readiness Test |
| CPAF | Cost Plus Award Fee | GS | Ground System |
| CVT | Calibration/Validation Team | GSD | Ground Sample(ing) Distance |
| CY | Calendar Year | GSFC | Goddard Space Flight Center |
| D+F | Determination and Findings | HIB | Harness Interface Box |
| DMC | Dark Mirror Coating | HQ | Headquarters |
| DoE | Design of Experiment | IAS | Image Assessment System |
| DPAS | Data Processing and Archive System | IBR | Integrated Baseline Review |
| DPMC | Directorate Program Management Council | IC | International Cooperator |
| ECP | Engineering Change Proposal | ICE | Independent Cost Estimate |
| EDC | EROS Data Center | IIGARSS | IEEE Geosciences and Remote Sensing Society |
| EDU | Engineer Developing Unit | IIA | Initial Implementation Agreement |
| ELV | Expendable Launch Vehicle | IOC | Initial Operational Capability |
| EOP | Executive Office of the President | IPY | International Polar Year |
| EPR | Engineering Peer Review | IRD | Interface Requirements Document |
| EPS | Electrical Power System | ISAL | Instrument Synthesis & Analysis Lab |
| EROS | Earth Resources Observation and Science | ISE | Instrument Support Electronics |
| ESD | Earth Science Division (at NASA HQ) | ITOS | Integrated Test & Operations System |
| EVM | Earned Value Management | I&T | Integration and Testing |
| FAR | Federal Acquisition Regulation | IV&V | Independent Verification & Validation |
| FEM | Finite Element Model | JCL | Joint Confidence Level |
| FFP | Firm Fixed Price | | |

Acronyms (2/2)



| | | | |
|-------------|---|-----------------|--|
| KDP | Key Decision Point | RFP | Request for Proposal |
| KSC | Kennedy Space Center | ROIC | Read Out Integrated Circuits |
| L8 | Landsat 8 | RSDO | Rapid Spacecraft Development Office |
| L9 | Landsat 9 | R/T | Real-Time |
| LCB | Load Control Board | RVS | Raytheon Vision Systems |
| LCCE | Life Cycle Cost Estimate | S&MA | Safety and Mission Assurance |
| LDCM | Landsat Data Continuity Mission | SA | Solar Array |
| LMO | Landsat Mission Operations | SAE | Storage and Archive Element |
| LRD | Launch Readiness Date | SCA | Sensor Chip Assembly |
| LSP | Launch Services Program | SDLC | System Development Life Cycle |
| L/V | Launch Vehicle | SDSU | South Dakota State University |
| MAR | Mission Assurance Requirements | SE | Systems Engineering |
| MCR | Mission Concept Review | SEB | Source Evaluation Board |
| MDR | Mission Definition Review | SiPIN | Silicon Pin |
| MEB | Main Electronics Box | SLI | Sustainable Land Imaging |
| MOC | Mission Operations Center | SMD | Science Mission Directorate (at NASA HQ) |
| MOE | Mission Operations Element | SMO | Systems Management Office |
| MOM | Mission Operations Manager | SNR | Signal to Noise Ratio |
| MRT | Mission Readiness Test | SOS | Spacecraft Observatory Simulator |
| MSR | Monthly Status Review | SRB | Standing Review Board |
| MTA | Material Test Assembly | SRR | System Requirements Review |
| MUX | Multiplexer | SSR | Solid State Recorder |
| NASA | National Aeronautics and Space Administration | STM | Safe to Mate |
| NEdT | Noise Equivalent Delta Temperature | SWIR | Shortwave Infrared |
| NPR | NASA Procedural Requirement | TA | Technical Authority |
| NVM | Nonvolatile Memory | TBD | To Be Determined |
| OLI | Operational Land Imager | TIB | Thermal Interface Board |
| OXCO | Oven Controlled Crystal Oscillator | TIM | Technical Interface Meeting |
| PACI | Payload and Attitude Control Interface | TIRS | Thermal Infrared Sensor |
| PLRA | Program-Level Requirements Appendix | TPI | Technical Performance Indicator |
| PMC | Program Management Council | UDL | Up/Down Link |
| PPBE | Planning, Programming, Budgeting, and Execution | ULA | United Launch Alliance |
| PSD | Power Spectral Density | UPE | User Portal Element |
| RAO | Resources Analysis Office | USGS | United States Geological Survey |
| RFI | Request for Information | VME | Versa Module Euro card |
| RFO | Request For Offer | VSWIR | Visible and Short Wave Infrared |
| | | WBS | Workforce Breakdown Structure |